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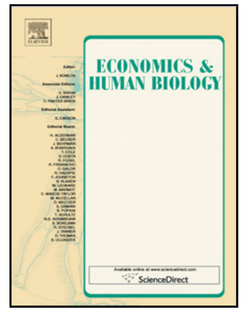

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Have Swiss adult males and females stopped growing taller? Evidence from the population-based nutrition survey menuCH, 2014/2015

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Highlights

- We use data from the population-based National Nutrition Survey (menuCH, 2014/15).
- We assess recent trends in measured height by year of birth for adult men/women.
- When self-reported, height was overestimated by about 1cm in men and women.
- Average measured height increased by 4.5-5.0cm since 1937.
- Starting with the 1970s birth years, height plateaued on 178cm (m) resp. 166cm (w).
- People from the Swiss Italian part and with lower educational level were shorter.

Abstract

Data from the National Nutrition Survey for adults (menuCH) allow for the assessment of recent trends in measured height by year of birth for adult men and women from a population-based sample. The aim of the present study was to test if – similarly to conscripts and schoolchildren – the Swiss adult population stopped growing taller in recent birth cohorts, and if so, when the change occurred.

We found that – when self-reported – height was overestimated on average by about 1cm in both men and women, with an increasing tendency with older age and with shorter height. Average measured height increased by 4.5-5.0cm for adult men and women between the birth years 1937-1949 and 1990-1995. However, this increase was not linear, and starting with the 1970s birth years, average height plateaued on a level of about 178cm for men and 166cm for women. Being born outside of Switzerland or adjustment for potential shrinkage with increasing age did not change this temporal pattern. We also found shorter average height among participants from the Italian part of Switzerland and those with lower educational level.

It remains unclear if the phenomenon of stabilisation affects all subgroups of the Swiss population. Future studies should combine a larger number of population-based surveys to enhance the sample size, for example, for people with a migration background or with different educational levels. Continuing growth monitoring needs to be performed to assess if environmental and demographic changes with an impact on body growth (adverse trends in nutrition, increasing social inequality in health, ethnic composition of the population) positively or negatively influence future trends in average height.

1. Introduction

For both past and modern societies, adult height is a useful marker of variation in cumulative net nutrition, biological deprivation, and standard of living between and within populations (Bogin, 1999; Perkins et al., 2016). The determinants of (adult) height include both genetics and environmental factors, and their complex interactions result in the phenotypic variation (Stulp and Barrett, 2016). According to twin studies in wealthy populations the genetic component of the variation in human height is estimated to be about 80% (Bogin, 1999). Family studies quantifying the resemblance in height among siblings or among parents and their off-spring resulted in lower coefficients of heritability (ca. 60%) (Wells and Stock, 2011). Moreover, not only genes are transferred from one generation to the next but also socioeconomic status and wealth (Bogin, 1999). Variation in average height over time and among sub-populations is considered to be driven by systematic differences in diet, disease environment, economic conditions, workload, and healthcare, which determine the extent to which individuals in these sub-populations realize their inherited genetic growth potential (Floud et al., 2009; McEvoy and Visscher, 2009; Steckel, 2009).

Average body height has increased in most developed countries over the past century but recent trends are divergent: Whereas the steady increase in average height has markedly slowed down or even plateaued over the past 20-40 birth years in Central and Northern Europe (Baten and Blum, 2014; Bentham et al., 2016; Danubio and Sanna, 2008; Franses, 1996; Hatton and Bray, 2010; Larnkaer et al., 2006; Schmidt et al., 1995; Schönbeck et al., 2013; Staub et al., 2016, 2011a; Stulp and Barrett, 2016; Susanne et al., 2001; van Zanden et al., 2014), South European populations have continued to become taller in recent birth decades (Deaton, 2007). The reasons for the height stabilization are not fully understood (McEvoy and Visscher, 2009). It is not clear whether this trend is short term or persistent, and whether it reflects a change in population composition (e.g. due to growing migration to Switzerland and other countries during the second half of the 20th century (Holenstein et al., 2018)) or whether, on the level of local populations, the genetic limits of height growth have been reached (Marck et al., 2017; Staub et al., 2011b).

Adult height in Switzerland and its historical development since the 19th century have been described in detail based on conscription data (Molinari et al., 1984; Staub et al., 2013) and until the 1930s, also for the adult population based on passport application, maternity hospital, and prisoners data sources (Koepke et al., 2018). Published anthropometric monitoring data for 18-21 year-old Swiss conscripts (Staub et al., 2016, 2014, 2011a) and 10-year-old schoolchildren from the cities of Zurich and Bern (Billeter, 1948; Lauener, 1947; Papandreou et al., 2017; Tschumper, 2014) suggest that the average heights of young adults and children have tended to stabilise since the 1960s or 1970s birth decades (Supplementary Figure 1). However, young adults and schoolchildren in particular may not have reached their final adult height, and less is known about recent trends among the general adult Swiss population.

One way to analyse trends in average height among the general adult population is to use population-based surveys that rely on systematic and representative samples. When displaying the average height of participants against their year of birth, changes in height become apparent. In Switzerland, this has been done for the Swiss Health Survey (SHS), the Swiss Household Panel (SHP) and for selected local surveys (Bentham et al., 2016; Faeh et al., 2008; Kues, 2010; Rohrmann et al., 2017). However, the two nationwide surveys (SHS and SHP) are based on self-reported height, which is known to be subject to overestimation (Bopp and Faeh, 2008; Kues, 2010).

Unlike these two older surveys, data from the National Nutrition Survey for adults (menuCH) released in 2017 allow for the assessment of recent trends in measured height by year of birth for adult men and women based on a population-based sample. The aim of the present study was to test if – similarly to conscripts and schoolchildren – the Swiss adult population stopped growing taller in recent birth cohorts, and if so, when the change occurred. Furthermore, we were interested in differences between self-reported and measured height. We explored whether the tendency for overestimation changes with age, and whether it depends on true (measured) height, as short individuals might have a stronger tendency to overestimate their height. Finally, we compared measured height between socio-demographic subgroups.

2. Materials and methods

Study Design

The cross-sectional population-based nutrition survey menuCH was conducted between 2014 and 2015 in ten study centres across Switzerland by the Institute of Social and Preventive Medicine of the University of Lausanne (IUMSP) and the Swiss Federal Food Safety and Veterinary Office (FSVO) in collaboration with Institute of Social and Preventive Medicine of Bern (ISPM) and Bern University of Applied Sciences (Bochud et al., 2017). Data are available upon submission of a short study description via the FSVO webpage (Bundesamt für Lebensmittelsicherheit und Veterinärwesen (BLV), 2018). The study was carried out in accordance with ethical standards defined in the Declaration of Helsinki and approved by the regional ethics lead committee in Lausanne (Protocol 26/13) as well as in all other study centres (Bochud et al., 2017). Written informed consent was obtained from each participant (Bochud et al., 2017).

Representativeness and sample weights

Study participants were drawn from a random stratified sample provided by the Federal Statistical Office (Chatelan et al., 2017). The 35 sampling strata (5x7) covered five age categories (18-24, 24-34, 35-49, 50-64, 65-75) and the seven Swiss "big regions" (*Grossregionen*) (Lake Geneva, Midlands, Northwest, Zurich, East, Central, and South), covering the three main language regions (German, French and Italian) and included 12 cantons (Chatelan et al., 2017). In menuCH, the net response rate was 38.0% (and relatively constant across age groups), but participants and non-participants were similar in terms of socio-demographic characteristics (sex, age, marital status, household size, nationality, and residential region) (Chatelan et al., 2017). We included all 2,086 individuals aged 18-75 years. To correct for non-response and sampling design, Pasquier et al. (Pasquier et al., 2017) provided calibrated official sample weights based on age group, sex, marital status, major region, nationality, and household size. The sample weights were developed in three steps: calculation of sample weight, correction of non-response, calibration of marginal totals (Pasquier et al., 2017). The detailed documentation about the weighting strategy is available from the official menuCH data repository of the Swiss Federal Food Safety and Veterinary Office (Pasquier et al., 2017). By using these sample weights, the results can be extrapolated to a population of 4,627,878 Swiss residents (Bochud et al., 2017; Pasquier et al., 2017). Since educational level was not available for non-participants, educational level was not part of the weighting strategy (Pasquier et al., 2017). In menuCH, the share of people with tertiary education was higher than among the general Swiss population (49.5% vs. 32% for women and 55.7% vs. 43% for men, respectively). This overrepresentation of better educated people was stronger among older than among younger age groups (grey shaded lines c) in Table 2) (Schweiz. Bundesamt für Statistik BFS, 2018). Further information about study design and data collection is provided elsewhere (Bochud et al., 2017; Chatelan et al., 2018, 2017; Krieger et al., 2018; Pestoni et al., 2019; Vinci et al., 2019).

Self-reported height and socio-demographic factors

In a first step, menuCH participants completed a general questionnaire prior to their interview and examination in one of the selected study centres (Bochud et al., 2017). The questionnaire contained information about socio-demographic/economic factors, health related issues including self-reported height and weight, and physical activity/eating behaviours. Educational level and sex were included in the analyses without any modification. Educational attainment was categorised into three levels: primary (participants with no degree or with a compulsory school degree, corresponding to International Standard Classification of Education (ISCED-2011) level 3), secondary (completed high school or apprenticeship, ISCED-2011 level 5), and tertiary (higher degree requiring a high school diploma, ISCED-2011 levels >=6) (UNESCO Institute of Statistics, 2012).

The Federal Statistical Office provided information on year of birth, administrative region of residence and country/region of birth as part of the sampling procedure. For regression analysis (see below), year of birth was categorized into six periods: 1937 (=max)-1949, 1950-1959, 1960-1969, 1970-1979, 1980-1989, and 1990-1995 (=min). “Big region” (*Grossregion*) followed the official but non-administrative division of the Swiss Federal Statistical Office (FSO) into Lake Geneva region, Midland, Northwest Switzerland, Zurich, Eastern Switzerland, Central Switzerland, and Ticino. Country of birth was classified into Switzerland (incl. Liechtenstein), Europe, and others (a more detailed categorisation was not possible due to small subsamples, see Supplementary Table 1).

Height measurement

In a second step, trained staff measured body height of the participants during their examination and interview in the study centres. Height was measured without shoes to the nearest 0.1cm according to WHO-MONICA protocol and using a Seca 220 telescopic stadiometer (Seca GmbH, Hamburg, Germany) (Bochud et al., 2017; World Health Organization (WHO), 1998). For seven participants (0.3%) measured height was not available (six handicapped participants and one participant refused to be measured). Thus, for these cases, we used self-reported height for analyses using sample weights.

Statistical analyses

Population characteristics

We computed sex-stratified descriptive statistics (absolute and relative frequencies, means, standard deviations (SD)) for socio-demographic subgroups (partially presented as supplementary material). These analyses were weighted according to the sample weights provided by Pasquier et al. (Chatelan et al., 2017).

Comparison of self-reported vs. measured height

Means were calculated for all participants that provided information on both measured and self-reported height (N=2,078). Due to missing measured height in seven cases (see above), we did not weight the results for this comparison (as weighting would in theory request to include all participants or new weights would have to be calculated). We plotted sex-stratified kernel density estimates and included the means as vertical lines. The absolute difference (Cole and Altman, 2017) between measured and self-reported height was calculated such that positive values indicate overestimated self-reported height. Temporal trends in the tendency to overestimate height were visualized by plotting individual differences between self-reported and measured height against age (for all participants). To see if shorter participants over-estimated their height to a higher degree than taller individuals did, we plotted individual differences between self-reported and measured height against measured height (for participants born after 1970, presumably showing no more secular increase in height). We added smoothed local polynomial regression lines (LOESS) for men and women.

Trends

General trends of average height across years of birth for men and women were visualized using smoothed LOESS regression (including 95% confidence intervals (CI)) based on the weighted data. Breakpoints for a possible stabilisation after the 1970s were estimated with segmented regression analysis for men and women. To check whether observed trends in population-level average height might be influenced by changing composition of study population (country of birth and educational background, see Supplementary Table 1) or by potential changes in height related to the age of the participants (still growing until the mid-20s or shrinkage after age 40), we compared the smoothed trends (LOESS regression) for the largest subgroups (based on the unweighted data) with the overall trend. For country of birth and educational levels, the trends of those men and women born in Switzerland and of people with tertiary educational level were compared to the overall trend separately. To see if the trends in very recent years change when the youngest and potentially still growing participants are excluded, we compared the smoothed trends for participants aged older than 23 years (Koepke et al., 2018) with the overall trend. To test if the trends in the early years change when taking potential shrinkage after age of 40 years into account (Bentham et al., 2016; Cline et al., 1989; Droyvold et al., 2006; Fernihough and McGovern, 2015; Peter et al., 2014; Sorkin et al., 1999), we compared trends of corrected measured height with trend for unadjusted measured and self-reported height. As correction factor for shrinkage, we used the numbers from two large samples from Austria and Norway (Droyvold et al., 2006; Peter et al., 2014): For participants with age 40-49, we added +0.7cm to their measured height for both sexes, for participants with age 50-59 +1cm for men and +1.3 for women, for participants with age 60-69 +1.3cm for men and +1.9cm for women, and for participants with age 70-79 years +1.8cm for men and +2.5cm for women. This correction fits the only published numbers from Switzerland, in which men lost 1.2cm until the age of 65 years and women lost 2.3cm until the age of 65 years in a small sample (N<50) from the 1950s (Büchi, 1950).

Linear regression

To quantify height differences between socio-demographic subgroups, we performed multivariable weighted linear regressions for men and women separately, using the official sample weights in the weighted least squares criterion. Reference groups were chosen based on size of the subgroups and the research question under study. Coefficients, 95% CI (based on actual sample size), and p-values were displayed using coefficient plots. In Supplementary Table 3 we also present the results from the unweighted regression (including bootstrap confidence intervals), showing that the results are very similar to those of weighted regression, and therefore not strongly affected by sample size in specific subgroups.

Software

All analyses were performed with R version 3.4.3 (2017 The R Foundation for Statistical Computing).

3. Results

Overall and sex-stratified socio-demographic characteristics of the study population are displayed in Table 1. A majority of the participants were born in Switzerland or Liechtenstein (66.3%), had a high (tertiary) educational level (52.6%), and were married (52.1%). The distributions for socio-demographic subgroups were very similar for both men and women. The oldest participants were born in 1937, the youngest in 1995. With the exception of the youngest participants born after 1990, the proportion of participants with tertiary educational level and not born in Switzerland increased from the older to the younger birth decades (Supplementary Table 1). The overall (weighted) mean of measured height was 176.7cm for men and 164.4cm for women of all ages, and the distributions were more or less symmetrical (skewness for men=0.0, women=0.1) (Supplementary Figure 2a). Crude average height for men born in the three decades after 1970 varied between 178.2cm and 178.7cm (SD 6.1cm-7.6cm), and for women between 165.4cm and 166.2cm (SD 5.9cm-7.5cm) (Supplementary Table 2).

Self-reported height was on average +1.1cm taller than measured height for men and +1.0cm for women (Supplementary Figure 2a). Supplementary Figure 2b shows that the difference (self-reported minus measured height) increased with age for both sexes: The higher the age the more positive was the difference and the more the participants overestimated their height. Supplementary Figure 2c shows that shorter men and women overestimated their height by a larger degree than taller men and women, even when only considering participants born after 1970 (presumably no more positive height trend and not yet markedly affected by shrinkage).

Men born in 1990-1995 were on average 4.6cm taller than those born in 1937-1949, for women the increase in average height was 4.9cm (Supplementary Table 2). The smoothed trends for both men and women show that this increase was not linear but took place only within the first three birth decades under study and plateaued from the 1970s birth years onwards (Figure 1a). Segmented regression analysis estimated a breakpoint with no more significant slope in increase of height after 1977 for men and 1969 for women.

Participants born in Switzerland and Liechtenstein were slightly taller compared to the overall level but showed the same temporal patterns (Figure 1b). Figure 1c shows that, when only potentially outgrown participants older than 23 years of age are considered, the apparently slight decrease in average height among the youngest participants disappeared. Figure 1d compares smoothed trends for measured height against self-reported and shrinking-adjusted height: Among older participants (early birth decades), the levels of shrinking-adjusted average height (the presumably original true height) were closer to that of self-reported than that of measured average height, even when the temporal patterns stayed the same.

The results from the multivariable linear regression revealed no significant changes in recent birth decades compared to the 1970s birth years for both men and women (Figure 2). Even if sample size for these subgroups was small, participants born in other countries than Switzerland and Europe were significantly shorter, -2.6cm (95% CI -4.5 to -0.7) for men and –5.7cm (95% CI -7.1 to -4.3) for women. There was a highly significant gradient in height across educational levels: Men with primary educational level were -4.7cm (95% CI -7.0 to -2.4) and women -3.6cm (95% CI -5.4 to -1.7) shorter than participants with tertiary education. Men and women from the Italian speaking part of Switzerland (Ticino) were -2.0cm (p=0.09) and -1.9cm (p=0.03) smaller than those from the other speaking regions, respectively. To see if the trend across age groups differ in relation to education level we extended the regression model and included an interaction term age category x education level. We did not find significant interactions (p=0.15 for men and p=0.81 for women).

4. Discussion

We analysed temporal trends in measured average height across birth cohorts among adult male and female participants of the National Nutrition Survey for adults (menuCH). When self-reported, height was overestimated on average by about 1cm in both men and women, with an increasing tendency with older age and with shorter height. We found an increase by 4.5-5.0cm on average measured height for adult men and women between the birth years 1937-1949 and 1990-1995. However, this increase was not linear, and starting with the 1970s birth years, average height showed a plateau on a level of about 178cm for men and 166cm for women. Being born outside of Switzerland or adjustment for potential shrinkage with increasing age did not change this temporal pattern. We also found shorter average height among participants from the Italian part of Switzerland and those with lower educational level.

The observed average height for adult males in the 1937-1949 (about 174cm) and 1990-1995 (about 178cm) birth cohorts matched well those of the conscripts from the same birth years (173.5cm in 1948 and 178.2cm in 1990-1995). We confirm that, similar to conscripts and schoolchildren (Supplementary Figure 1), adult height also plateaued in recent birth decades. The plateauing in the birth years following 1970 was also observed in self-reported adult heights from SHP participants (Kues, 2010). Likewise, the shorter average height in the Italian speaking region of Switzerland has already been reported by other studies at the level of regions, cantons, districts or ZIP codes, the same accounts for the socio-economic gradient in average height (Hermanussen et al., 2014; Kues, 2010; Rühli et al., 2008; Staub et al., 2013). These findings are also in line with more general regional differences between neighbouring European countries (i.e. taller people in Germany and France, compared to Italy) (Bentham et al., 2016; Lehmann et al., 2017).

The reasons for plateauing in average height despite of further growing living standards, as measured e.g. by GDP per capita or longevity, in Northern and Central Europe as well as in other Westernized countries are not yet fully understood (Bentham et al., 2016). The most supported hypothesis is that an increasing share of individuals among these populations in a stable food and health environment reach their full genetic growth potential (Marck et al., 2017). According to this hypothesis, height would be a good indicator for deficiency, but not for excess (Steckel, 2008, 2005). However, environmental changes such as increasing social inequalities in health (Stringhini et al., 2017) or changes in the quality of the diet such as stabilising shares of proteins could play a role as well (e.g., milk consumption in Switzerland has decreased during the past years) (Del Gobbo et al., 2015; Morency et al., 2017). Most recently, the increasing share of newborns with low birth weight as a consequence of improving reproductive health across the past decades has been associated with plateauing height trends in Japan (Normile, 2018). Further research is needed to assess if trends in size at birth can be associated with trends in adults. Last, but not least, the composition of the Swiss population changed over time, in terms of migration background (the countries and world regions of origin vary over time since Switzerland became a classical immigration country) or educational levels (the share of women with tertiary education increased across birth cohorts in the study population at hand). The contribution of such factors has not been assessed thus far. Analyses of recent height trends were predominantly done by comparing different countries. Much less is known about trends among subgroups within populations. Because studies like menuCH were not designed to explore these issues, sample size in such single studies is limited to assess such subgroup questions on height trends.

Population-based economic or health surveys are frequently used to analyse temporal trends of adult height in the second half of the 20th century in various countries (Bentham et al., 2016; Gausman et al., 2018; Hatton and Bray, 2010). However, such studies are subjected to several methodological limitations: young adult participants have not completed their height growth at the time when the survey is conducted, whereas older participants may lose some of their adult height due to age-related shrinkage. The present study attempted to account for both effects. However, menuCH does not include follow-up assessments and measurements of height. Moreover, there generally may be methodological issues regarding upright posture when measuring older people in surveys. Thus, the importance of shrinkage and/or posture problems with ageing could only be estimated based on the literature. Our results suggest that at least part of the difference between measured and self-reported height could be explained by shrinkage or posture problems. For example, older men might report their height as it was measured decades ago during military conscription at age 19 (Faeh et al., 2008). This has implications for overweight and obesity research when it concerns the calculation of body mass index or waist-to-height-ratio in elderly people: Which height is more accurate, current height or height before shrinking that may be closer to actual self-reported height (Danubio et al., 2008; Sorkin et al., 1999) ?

The present study comes with limitations. The relatively small sample size of menuCH did not allow for analysing subgroups with specific migration background (e.g., Northern vs. Southern Europe). Some of the variables available in menuCH are limited: Regional information other than “Big region” was not available with a large enough sample size. We therefore could not control for urban vs. rural differences. Sample size was considered too small to estimate robust analyses of distributional changes (e.g. relation between the standard deviation or the 5th/95th percentiles and the mean) across birth cohorts (Gausman et al., 2018). Also, it cannot be excluded that the older participants are subjected to survivor bias (i.e. those who reach old age are taller than those who died earlier). Furthermore, especially for health surveys and depending on the topic, the motivation to participate and the interest in the topic can differ, for example, depending on the socio-economic background (e.g., selection and healthy participant bias).

Response rate in menuCH was relatively low (38%), even though comparable to other European food surveys (Chatelan et al., 2017; Heuer et al., 2015; Leclercq et al., 2009). The sampling weights adjusted for the characteristics of non-responders, and participants and non-participants were similar in terms of socio-demographic characteristics (sex, age, marital status, household size, nationality, and residential region) (Chatelan et al., 2017). However, since educational level was not available for non-participants, educational level was not part of the weighting strategy (Pasquier et al., 2017). The share of people with tertiary education was higher among menuCH participants than in the general Swiss population, in particular among older participants (Table 2) (Schweiz. Bundesamt für Statistik BFS, 2018). This bias regarding educational level of participants in health surveys is well-know also for Switzerland (Bopp et al., 2014; Volken, 2013).

This education level bias can lead to questions connected with identification (Manski, 2007). In theory, population statistics can be consistently estimated by reweighting the sample statistics if it is known in which way the sample is not representative and if the research is directed at estimating population descriptive statistics (Solon et al., 2015). However, in the present case the education variable was not part of the stratification process (Chatelan et al., 2017; Pasquier et al., 2017). In other words, the present sample is better educated than the population and there are no weighting probabilities to solve this problem. The underrepresentation of lower educated people may thus lead to biased and inconsistent estimates if the individuals who did not participate were systematically different from those who did (Manski, 2007). However, not all types of non-random sampling cause bias or inconsistency (Wooldridge, 2013). In the present case the sample is selected on the educational level and it is therefore a sample selection based on an independent variable (also called exogenous sample selection). The estimates can be unbiased and consistent if the linear model is the same for any subset of the population described by the independent variables. Or, in other words: if the education has a constant effect on body height across birth year categories.

In the case of menuCH, we did not find significant interaction between age category and education level in our regression, indicating that height trends across age groups did not differ in relation to education level. To further estimate by how much height was overestimated due to the overrepresentation of better educated people we also compared mean height for birth years and the education level distributions from the sample with the projected mean height if the sample would have the distribution from the population (grey shaded lines d) in Table 2). For men, overestimation was greatest in the older age groups. For women, overestimation was generally smaller than for men. Among both sexes, height overestimation due to overrepresentation of better educated men and women did not become smaller between the two youngest age categories (indicating that a contribution to the plateauing phenomenon is not likely). Thus, we conclude that our results are not excessively distorted, despite the educational level selection bias.

Conclusion and Outlook

We conclude that, in Switzerland, the general adult population has stopped becoming taller over the past three to four birth decades. However, it remains unclear if this phenomenon affects all subgroups of the Swiss population. Future studies should, thus, combine a larger number of population-based surveys to enhance the sample size, for example, for people with a migration background or with different educational levels. Furthermore, follow-up studies of population-based surveys should include precise height measurements especially in older participants in order to better understand the effect of shrinkage and/or posture problems on height. Last, but not least, continuing growth monitoring needs to be performed. It would be important to assess if environmental and demographic changes with an impact on body growth (adverse trends in nutrition, increasing social inequality in health, ethnic composition of the population) positively or negatively influence future trends in average height.

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Tables

Table 1: Sample distribution and frequencies for socio-demographic subgroups in menuCH, unweighted results on the left, weighted results on the right. Relative frequencies are weighted for age group, sex, major region, and nationality. No information on missings = 0 missings.

	Unweighted sample			Weighted sample		
	Overall	Men	Women	Overall	Men	Women
	2086	946	1140	4627878	2305141	2322737
Year of birth	N	N	N	%	%	%
1937-1949	352	172	180	14.7	15.7	13.7
1950-1959	349	169	180	16.5	17	15.9
1960-1969	455	202	253	21.5	21.4	21.5
1970-1979	362	161	201	19.2	18.7	19.8
1980-1989	367	157	210	19.3	18.6	20
1990-1995	201	85	116	8.8	8.6	9.1
Administrative region	N	N	N	%	%	%
Lake Geneva region (French speaking)	405	162	243	19.4	17.1	21.6
Midland	387	171	216	20	19.9	20
Northwest Switzerland	304	136	168	17.8	18.5	17.2
Zurich	304	139	165	23.2	22.7	23.6
Eastern Switzerland	251	142	109	7.9	10	5.8
Central Switzerland	219	103	116	6.2	6.4	6.1
Ticino (Italian speaking)	216	93	123	5.6	5.3	5.8
Country of birth	N	N	N	%	%	%
Switzerland and Liechtenstein	1586	727	859	66.3	67.2	65.4
Europe	368	167	201	25.6	25.4	25.7
Others	122	48	74	7.6	6.8	8.4
Missing	10	4	6	0.6	0.6	0.6
Educational level	N	N	N	%	%	%
Primary	89	38	51	4.6	4.7	4.5
Secondary	980	389	591	42.7	39.4	45.9
Tertiary	1013	517	496	52.6	55.7	49.5
Missing	4	2	2	0.2	0.2	0.1

Table 2: Distribution of educational levels in each age/birthyear group and implications for the estimation of mean height. a) Distribution of educational levels in the menuCH sample (% of respondents). b) Distribution (%) in a larger and more representative sample of the Swiss population (Schweiz. Bundesamt für Statistik BFS, 2018). c) Ratio between each level's percentage in the sample and in the population - a ratio > 1 indicates over-representation. d) Over-estimation of mean height (in cm) due to the over-representation of tertiary education in the sample: Observed mean height per age group in the sample; Projected (estimated) mean height in the population, calculated by multiplying the observed mean height in the sample with the population distribution of educational levels; Difference between sample means and population estimates.

Men

a) Sample	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Primary	2.9	3.6	5.0	1.9	2.6
Secondary	43.0	39.6	37.1	31.7	36.9
Tertiary	54.1	56.8	57.9	65.8	60.5

b) Population	**65+**	**55-64**	**45-54**	**35-44**	**25-34**
Primary	13.1	12.6	11.2	11	8.4
Secondary	67.9	66.1	61.1	56.1	56.6
Tertiary	18.8	21.3	26.8	33	35.1

c) Ratio	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Primary	0.2	0.3	0.4	0.2	0.3
Secondary	0.6	0.6	0.6	0.6	0.7
Tertiary	2.9	2.7	2.2	2.0	1.7

d) Overest.	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Sample (observed)	174.1	174.2	176.9	178.5	178.5
Population (projected)	172.0	173.8	174.6	177.8	177.8
Difference	2.1	0.4	2.3	0.7	0.8

Women

a) Sample	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Primary	5.0	7.0	6.0	3.0	1.0
Secondary	66.0	59.0	51.0	41.0	30.0
Tertiary	29.0	34.0	42.0	55.0	69.0

b) Population	**65+**	**55-64**	**45-54**	**35-44**	**25-34**
Primary	33.1	19.9	15.2	11.8	7.8
Secondary	59.3	65.4	65.4	56.5	52
Tertiary	7.6	14.7	19.6	31.6	40.2

c) Ratio	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Primary	0.2	0.3	0.4	0.3	0.1
Secondary	1.1	0.9	0.8	0.7	0.6
Tertiary	3.9	2.3	2.2	1.7	1.7

d) Overest.	**1937-1949**	**1950-1959**	**1960-1969**	**1970-1979**	**1980-1989**
Sample (observed)	160.7	163.3	164.6	165.5	166.2
Population (projected)	160.5	162.6	164.5	164.6	165.5
Difference	0.1	0.7	0.2	0.9	0.7

Figure 1: a) Smoothed trends (LOESS regression fitting) for weighted vs. unweighted adult male and female height (N=2086). Breakpoints and 95%CI as estimated via segmented regressions are displayed at the bottom. (b) Temporal trends according to place of birth (N=1583 in Switzerland only vs. everyone). c) Temporal trends of potentially outgrown adults (N=1905 age>23) vs. everyone. d) Temporal trends for self-reported and shrinkage-adjusted average height vs. everyone. e) Temporal trends for tertiary educational level vs. everyone.

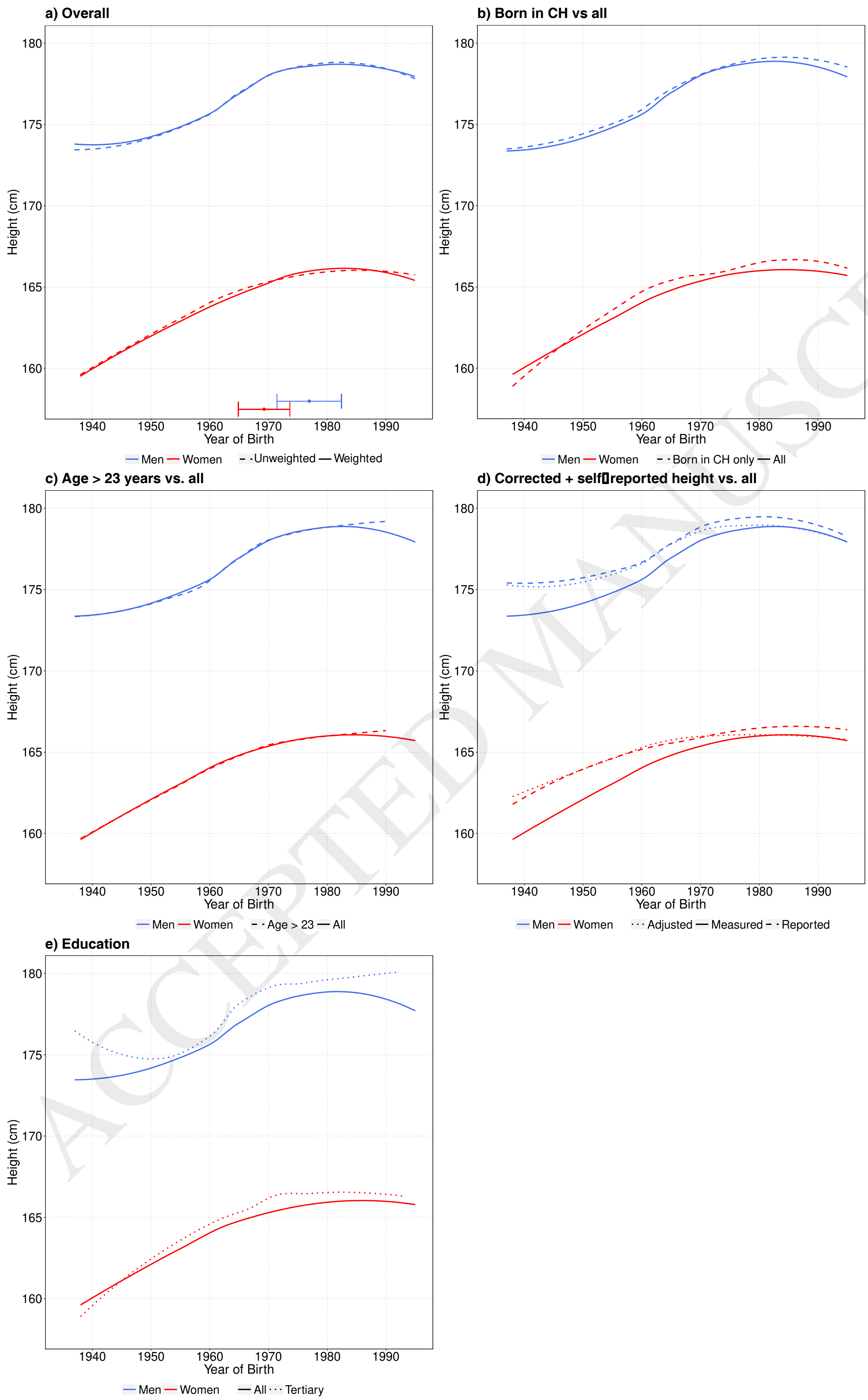
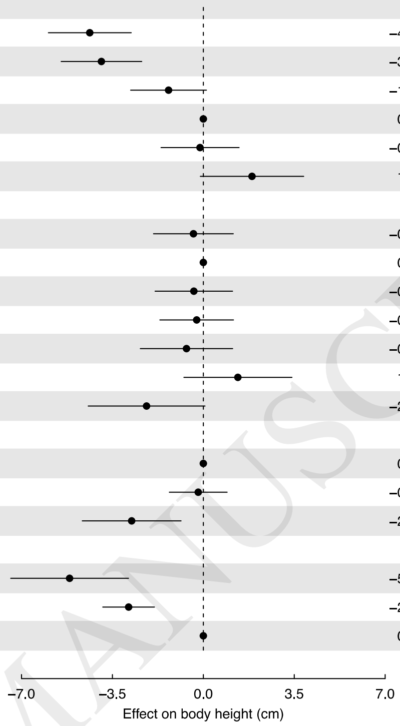


Figure 2: Results of the multivariable linear regressions for men (top) and women (bottom), based on the weighted data (for unweighted results see Supplementary Table 2). Missing values were included in the regression model as missing category but are not shown. CI=Confidence Intervals, %=relative frequency of categories within variables (share of missings not shown).

Men

Predictors and categories	%	Regression coefficient (with 95% CI)	p–value
Year of birth			
1937–1949	15.7	−4.37 (−5.97 to −2.78)	0.00
1950–1959	17.0	−3.92 (−5.48 to −2.37)	0.00
1960–1969	21.4	−1.34 (−2.80 to 0.12)	0.07
1970–1979	18.7	0.00	
1980–1989	18.6	−0.13 (−1.63 to 1.38)	0.87
1990–1995	8.6	1.87 (−0.12 to 3.87)	0.07
Big region			
Lake Geneva region	17.1	−0.38 (−1.92 to 1.16)	0.63
Midland	19.9	0.00	
Northwest Switzerland	18.5	−0.37 (−1.86 to 1.13)	0.63
Zurich	22.7	−0.26 (−1.67 to 1.16)	0.72
Eastern Switzerland	10.0	−0.65 (−2.43 to 1.13)	0.48
Central Switzerland	6.4	1.33 (−0.75 to 3.41)	0.21
Ticino	5.3	−2.18 (−4.43 to 0.06)	0.06
Country of birth			
Switzerland and Liechtenstein	67.2	0.00	
Europe	25.4	−0.20 (−1.31 to 0.92)	0.73
Others	6.8	−2.76 (−4.66 to −0.86)	0.00
Educational level			
Primary	4.7	−5.15 (−7.42 to −2.88)	0.00
Secondary	39.4	−2.88 (−3.87 to −1.88)	0.00
Tertiary	55.7	0.00	



Women

Predictors and categories	%	Regression coefficient (with 95% CI)	p–value
Year of birth			
1937–1949	13.7	−5.23 (−6.54 to −3.92)	0.00
1950–1959	15.9	−2.42 (−3.68 to −1.16)	0.00
1960–1969	21.5	−1.21 (−2.35 to −0.07)	0.04
1970–1979	19.8	0.00	
1980–1989	20.0	0.33 (−0.84 to 1.49)	0.58
1990–1995	9.1	−0.16 (−1.67 to 1.35)	0.84
Big region			
Lake Geneva region	21.6	0.31 (−0.84 to 1.46)	0.60
Midland	20.0	0.00	
Northwest Switzerland	17.2	−0.55 (−1.75 to 0.65)	0.37
Zurich	23.6	0.19 (−0.93 to 1.32)	0.74
Eastern Switzerland	5.8	−0.20 (−1.92 to 1.51)	0.82
Central Switzerland	6.1	1.24 (−0.45 to 2.93)	0.15
Ticino	5.8	−1.87 (−3.60 to −0.14)	0.03
Country of birth			
Switzerland and Liechtenstein	65.4	0.00	
Europe	25.7	−0.38 (−1.29 to 0.52)	0.41
Others	8.4	−5.68 (−7.06 to −4.30)	0.00
Educational level			
Primary	4.5	−3.80 (−5.64 to −1.96)	0.00
Secondary	45.9	−1.18 (−2.00 to −0.36)	0.01
Tertiary	49.5	0.00